

Solubilization of Rock Phosphate by *Penicillium bilaiae* – Soil Phosphorus Management in Organic Crop Production –

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Abstract

Phosphorus deficiency is a major problem on most organic farms in Saskatchewan. Phosphorus levels have been decreasing in soil due to crop removal without the use of amendments to re-supply P to the soil. Rock phosphates are naturally occurring phosphorus minerals, generally accepted as phosphorus amendments in organic crop production. *Penicillium bilaiae* (JumpStart[®]) is a fungal inoculant originally isolated from southern Alberta soils. *P. bilaiae* is thought to solubilize phosphorus minerals in soil and to enhance phosphorus availability to plants. There are several hypothesized mechanisms by which microorganisms enhance the dissolution of phosphorus minerals. For calcium phosphorus minerals such as rock phosphates, two mechanisms are considered most likely: 1) acidification by the exuded protons and organic acids and by the production of carbon dioxide, and 2) the complexation of cation partners of phosphorus by the exuded organic acids. This paper reviews properties of rock phosphates and *P. bilaiae*, and discusses potential phosphorus-solubilization mechanisms of *P. bilaiae*. Finally, this paper introduces experiments that investigate phosphorus-solubilization mechanisms of *P. bilaiae*.

Introduction

Phosphorus (P) availability is generally low on organic farms. Entz et al. (2001) conducted a survey on 14 organic farms in the eastern portion of the northern Great Plains. The average soil P level was 15 kg ha⁻¹, which was substantially lower than that found on the conventional farms nearby. Without sufficient amendments to re-supply P to the soil, cultivation potentially causes

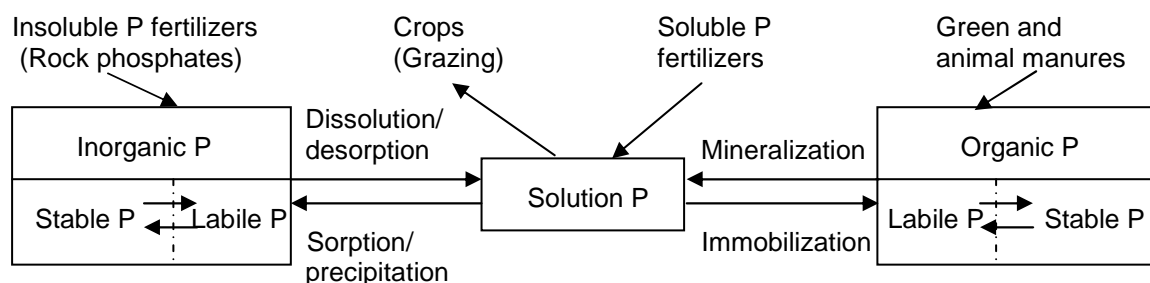


Figure 1. Phosphorus transformation in soils [Modified from Robertson (1980)].

decreases in soil P levels over time. Green and animal manures and rock phosphates (RPs) are generally accepted P amendments in organic systems. However, P availability from these amendments is restricted by many processes, such as mineralization/immobilization, desorption/adsorption, and dissolution/precipitation (Figure 1).

The role of rock phosphate as a long-term P amendment is the focus of this paper. In calcareous soils, which are dominant in Saskatchewan, high pH and calcium carbonate (CaCO_3) content limit the dissolution of RPs. The inoculation of *Penicillium bilaiae* is considered as a natural agent to enhance the dissolution of RPs, i.e., a short-term P management.

Rock Phosphates

Rock phosphates are naturally occurring phosphate minerals. Commercial RPs are mainly carbonate apatite with varying degree of substitution of carbonate for phosphate. The carbonate substitution causes amorphous structure in the RPs, and increases the solubility. In addition to RP properties, soil type, site-specific climate, and the growth of plants and microorganisms affect the dissolution of RPs in soils (Figure 2).

In calcareous soils, high pH and CaCO_3 content are major factors limiting agronomic efficiency of RPs. In rhizosphere soil, however, plant and microbial exudates may increase the availability of P from RPs. For example, protons (H^+), released as a result of cation uptake by plants and microorganisms, directly decrease pH in their environment. Exuded organic acids also have been reported to dissolve P minerals directly and/or through complexation of the cationic partners of P, which are mainly Ca in RPs.

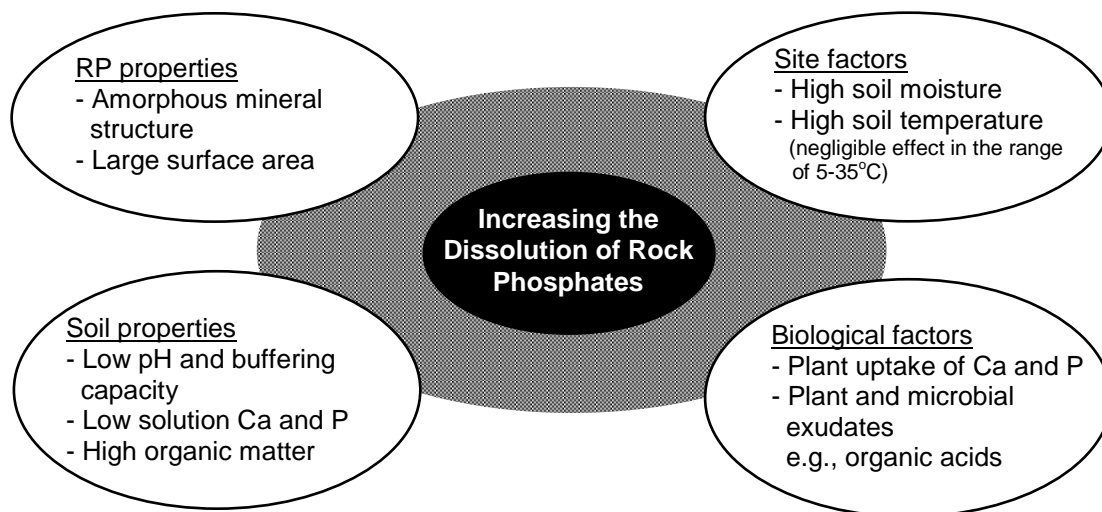


Figure 2. Factors increasing the dissolution of rock phosphates.

Penicillium bilaiae

Penicillium bilaiae was originally isolated from soils in southern Alberta by Kucey (1983). Studies have shown that *P. bilaiae* solubilizes more RP in culture solution than other P-solubilizing microorganisms (Kucey, 1983; Asea et al., 1988). Inoculation with *P. bilaiae*

increased P uptake by several plant species, including wheat (Gleddie et al., 1991) (Table 1), canola (Gleddie et al., 1993), and alfalfa (Schlechte et al., 1996). However, it is not clearly understood how *P. bilaiae* solubilizes P minerals and enhances P uptake by plants.

Table 1. Effect of Seed Row Inoculation of Soil with *Penicillium bilaiae* on Wheat Grain Yield and P Uptake under Field Conditions. [†]

Treatment	Grain yield g m ⁻²		P uptake g m ⁻²	
	1987	1988	1987	1988
Control	181	201	0.79	0.82
RP [‡]	186	208	0.81	0.86
<i>P. bilaiae</i> [¶]	230	220	1.06	0.94
RP [‡] + <i>P. bilaiae</i> [¶]	220	231	0.91	0.92

[†] Derived from Kucey (1987) and Kucey (1988).

[‡] Rock phosphate: 20 kg P ha⁻¹ equivalent.

[¶] 2.0 g fresh weight inoculum per 2-m row length.

Potential P-solubilization Mechanisms by *Penicillium bilaiae* in Calcareous Soils

Many studies have investigated mechanisms in which P-solubilizing fungi enhance the mobility of P to plants (reviewed by Whitelaw (2000)). Most accepted P-solubilization mechanisms used by these fungi are: 1) acidification by exuded H⁺ and organic acids, and through the production of carbon dioxide (CO₂), 2) complexation of cation partners of P by the exuded organic acids, and 3) ligand exchange (i.e., exchange of P) by the exuded organic acids (reviewed by Gulden and Vessey (2000)). In calcareous soils, which generally carry a negative charge, ligand exchange is negligible.

Previous studies have shown consistent pH reduction in the solid and liquid culture of *P. bilaiae* (Asea et al., 1988; Cunningham and Kuiack, 1992). The larger pH reduction was related to assimilation of ammonium by *P. bilaiae* rather than nitrate. Also, citrate and oxalate were detected as the major acidic metabolites in the sucrose nitrate liquid medium of *P. bilaiae* (Cunningham and Kuiack, 1992). Because P-solubilization by HCl alone did not totally explain the solubilization observed with *P. bilaiae* (Table 2), it was suggested that organic acid metabolites might be involved in the P-solubilization occurring with *P. bilaiae*.

Table 2. Solution pH and P Solubilized from Rock Phosphate by *Penicillium bilaiae*, and by the addition of HCl. [†]

pH [‡]	P in solution (mg)		Major components in liquid medium
	with <i>P. bilaiae</i>	with HCl	
3.7	14.2	4.5	Glucose, ammonium, nitrate
4.0	2.5	2.1	Glucose, nitrate

[†] Derived from Asea et al. (1988)

[‡] Initial pH=7.2.

Experiments for Investigating P-Solubilization Mechanisms by *Penicillium bilaiae*

The objectives of experiments are to understand mechanisms by which *P. bilaiae* solubilizes RP in the solution culture, and to test the hypothesized mechanisms from the results of solution culture experiments under field conditions.

For the first objective, *P. bilaiae* will be grown in nutrient solution containing RP. Measured pH and amounts of organic acids will be examined for their correlation with the P solubilized from RP. A similar experiment will be conducted with the addition of a buffer, in order to investigate the effect of buffering capacity on the P-solubilization by *P. bilaiae*. A computer program, such as MINTEQA2 and SOILCHEM, will be used to estimate complexation abilities of organic acids, i.e., percentages of organic acids that complex with Ca under the experimental conditions. This computer simulation may elucidate how pH buffering affects the complexation abilities of organic acids. If there is a correlation between P-solubilization and organic acid production, this P-solubilization mechanism will be confirmed by the measurement of P solubilized by the addition of organic acids alone.

For the second objective, P uptake by wheat, which is applied with *P. bilaiae* and RP, will be determined for two organically managed soils with different buffering capacities. These organic sites are located in Vonda and Scott, Saskatchewan.

Summary

The application of RP and *P. bilaiae* has the potential to maintain soil P levels and enhance plant P availability in organic crop production. The potential mechanisms of P-solubilization by *P. bilaiae* in calcareous soils are 1) the acidification by the exuded protons and organic acids and through the production of carbon dioxide, and 2) the complexation of cation partners of P by the exuded organic acids. These mechanisms need to be investigated with consideration of the buffering capacity of calcareous soils.

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